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Screening Tests for Pulmonary Function Abnormality

by Albert Miller*

Simple tests based on a voluntary forced expiration can detect pulmonary impairment of occupational or environmental origin earlier than can be done using clinical or radiographic examination. These tests are easily performed and repeated, require little time and can be readily set up in the field. Flow impairment ("obstructive") has conventionally been measured by the forced expiratory volume—1 sec (FEV_1); earlier changes, in the small airways are more likely to be detected by the maximal midexpiratory flow (MMF) and the maximum expiratory flow-volume (MEFV) curve at low lung volumes. Volume impairment ("restrictive") is detected by the forced vital capacity (FVC) from which the preceding measurements are made.

Two basic types of pulmonary impairment, airway and parenchymal, may result from occupational exposure. Spirometry, which measures lung volumes (other than functional residual capacity, total lung capacity, and residual volume) and various flow rates (the most useful of which are the forced expiratory volume in 1 sec or FEV_1, and the maximal midexpiratory flow or MMF), can reflect both types of impairment. In recent years, more specific tests have also been adapted for use in screening.

Screening tests must: be easily understood and performed; be readily repeated without waiting for clearance of a gas; be free of pain or discomfort; utilize rugged equipment which can be easily transported and set up in the field; require little time; and must have well defined predicted or "normal" values. Many standard pulmonary function tests do not meet these criteria.

Airway or Flow Impairment

Airway or flow impairment ("obstructive") occurs with sensitization to organic dusts, e.g., cotton, flax or hemp or to proteolytic enzymes in detergents. "Small airway" (bronchioles < 2 mm in diameter) obstruction is a consequence of exposure to small particles, since these particles settle out in the respiratory bronchioles where air flow normally slows. Small airway obstruction is an early change in coal workers' pneumoconiosis and asbestosis.

The FEV_1, the amount of air expelled in 1 sec when the subject breathes out as rapidly as he can following a maximum inspiration, may be expressed in liters, as percentage predicted volume, or as percentage of the forced vital capacity; this is the most used and best known test of air flow but is insensitive to obstruction in the small airways.

The maximal midexpiratory flow (MMF) is the mean flow over the mid-50% of the forced vital capacity; it is expressed as liters per second or percentage of predicted flow rate. It requires graphic analysis of the forced vital capacity (FVC) curve or an automated device with a memory. It reflects flow at lower (below functional residual capacity) lung volumes and may be abnormal when FEV_1 is normal (*1*).

The maximum expiratory flow volume (MEFV) curve displays expiratory flow against

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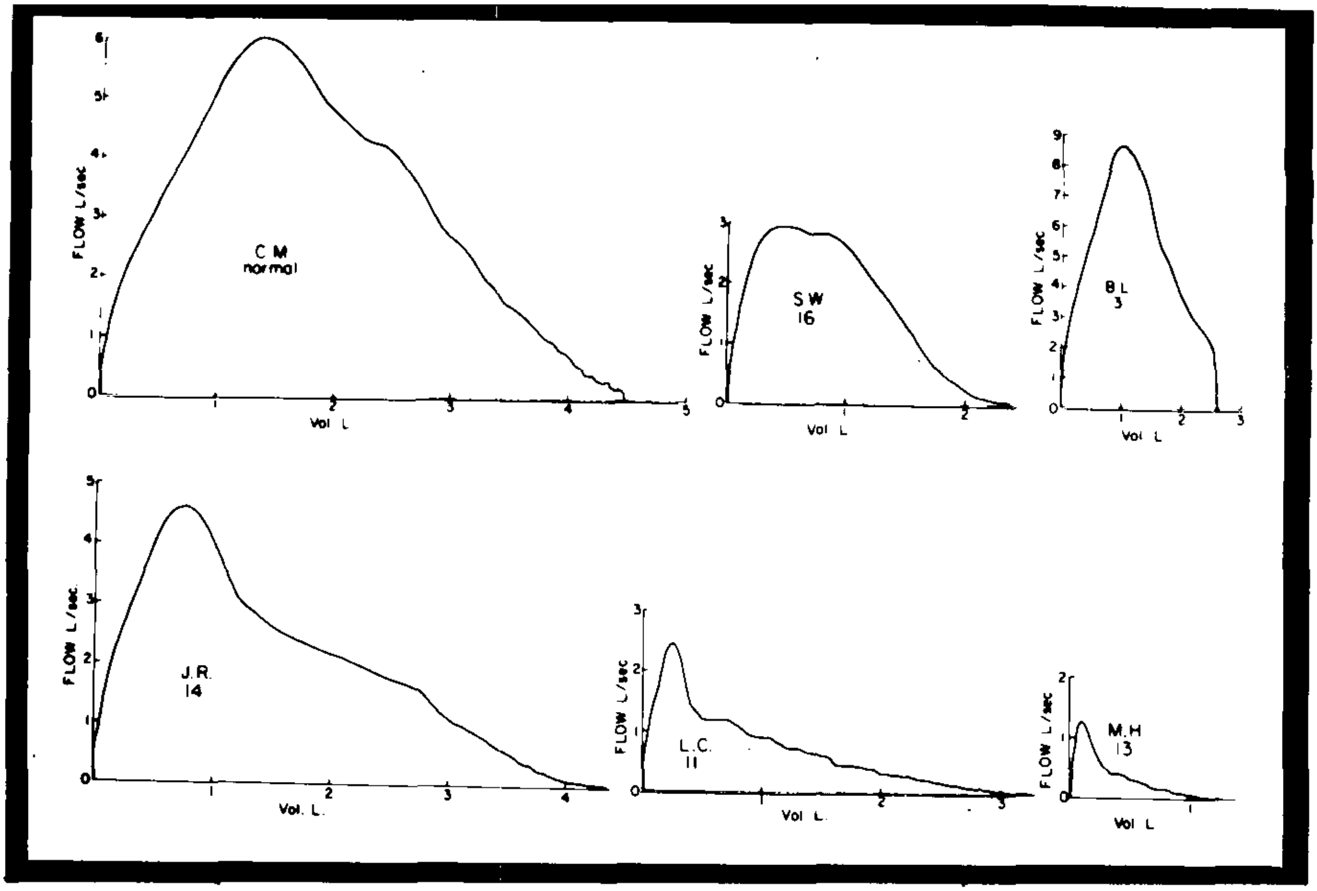

FIGURE 1. Representative flow-volume curves showing (CM) normal configuration; (SW) curves seen in restrictive impairment, with proportional loss of flow and volume and (BL) selective loss of volume, and (JR, LC, and MH) progressive flow impairment.

lung volume; flow at any lung volume can be seen (Fig. 1). Flow rates when all save 50% and 25% of the FVC have been expired (FEF_{50} and FEF_{25}) reflect both the caliber of the small airways and the elastic recoil of the lungs; both of these functions are impaired in emphysema. These flow rates may be compared to normal values or expressed as a ratio to FVC.

Although the MEFV curve has not yet been widely used in occupational surveys, it was recently employed in a survey of vinyl chloride workers (*2*). It has been used to detect work-related acute changes in the small airways in workers exposed to such different materials as toluene diisocyanate (*3*) and cotton dust (*4*). Changes in the shape of the curve or in flows at or below 50% of FVC were much more marked than changes in FVC or FEV_1 and were most closely related to symptoms of chest tightness ("Monday morning dyspnea"). A smaller percentage of workers who demonstrated only increased airway resistance on body plethysmography were felt to be large airway responders. The symptomatic small airway responders are most likely to develop chronic irreversible airway obstruction (*4*).

The closing volume is considered a specific test of small airway function. It is the volume at which basal lung segments close; this is seen as an upswing in the concentration of the xenon, helium or argon inhaled as a bolus at residual volume (bolus methods) or in N_2 when 100% oxygen is inhaled (resident air method). The test requires inhalation of a gas other than ambient air and a specific gas analyzer. The respiratory maneuver is more complicated, and time must be allowed for clearance of the gas before the test can be repeated. In addition, uninterpretable tests are obtained in a certain percentage of subjects (*5*).

Parenchymal or Volume Impairment

Parenchymal or volume impairment ("restrictive") occurs with exposure to mineral dusts, e.g., asbestos or beryllium.

The vital capacity is a relatively sensitive indicator and is an ideal screening test; a decrease in vital capacity (VC) precedes radiographic change (*6*).

Air flow (FEV_1, MMF, FEF_{50}, and FEF_{25}) may be maintained or may decrease proportionately to the decrease in lung volume; flow–volume ratios are normal or increased. The MEFV curve may be characteristic (Fig. 1).

Diffusing capacity for CO may be impaired before change in vital capacity; automated apparatus helps the investigator study a large number of subjects, but special gases and analyzers must be available and time allowed before the test can be repeated, so that this is not an ideal field test.

Table 1 lists the tests obtained on approximately 800 vinyl chloride–poly(vinyl chloride) workers in Niagara Falls, N.Y., and South Charleston, W. Va. The tests used for statistical analysis are indicated.

For spirometry, a Systems Research Laboratories Predictive Pulmonary Screener (Model M-12) was used (Fig. 2). The flow signal obtained by a heated-wire anemometer which was linearized over the full range of flows was integrated, then displayed digitally and graphically recorded against time. Although flow-volume curves could be obtained from this instrument, they were obtained by use of a separate system, a Vertek 3500 Fleish pneumotachygraph, and recording both flow and integrated volume signals on a Houston *X–Y* plotter. Each instrument was calibrated in the laboratory before and after the survey and in the field against the other instrument as well as by using a calibrating syringe, 1–10 l./sec rotameter, and known normal subjects. Subjects were standing and nose clips were placed. The best of at least three forced expirations was used unless the initial spirographic or flow-volume curve was normal or the first two curves agreed within 10% of each other. In such cases, additional efforts were considered unnecessary and were omitted in order to save time in the field.

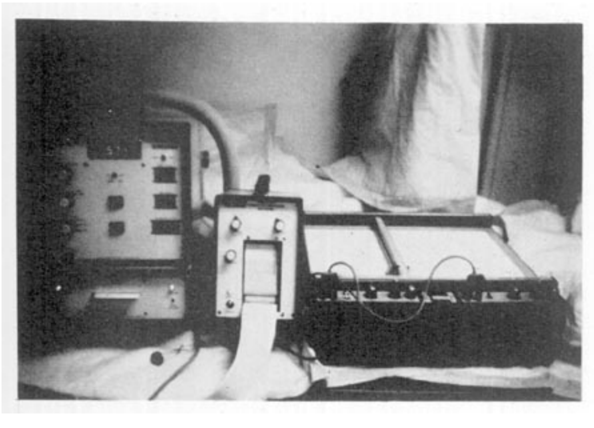

FIGURE 2. Automated device which supplies digital read- and print-outs of all spirometric tests and predicted value shown in Table 1, as well as flow and integrated volume signals which are plotted to provide spirographic and maximum expiratory flow-volume curves.

Table 1. Pulmonary function tests performed by 800 vinyl chloride workers.

Spirometric test
Forced vital capacity[a]
Slow vital capacity (if FVC reduced without evidence of impaired flow)[a]
FEV_1
FEV_1/FVC[a]
FEV_3/FVC
MMF[a]
Mid-expiratory time
Flow volume curve
Peak flow rate
Configuration
FEF at 50% FVC
FEF 50%/FVC
FEF at 25% FVC (75% expired)
FEF 25%/FVC[a]

[a] Subjected to statistical anyalsis.

If the forced vital capacity (FVC) was decreased but indices of air flow were normal, slow vital capacity (SVC) maneuvers were performed. Predicted values for vital capacity and maximum mid-expiratory flow (MMF) were those of Morris (*7*); the MMF was considered normal if it was $\geqq$ 75% of predicted and the vital capacity if it was $\geqq$ 80% of predicted values. The 1-sec forced expiratory volume (FEV_1) was considered normal if it was $\geqq$ 75% of FVC. The forced expiratory flow after all but 25% of the FVC had been expired (FEF_{25}) was considered normal if it was $\geqq$ 30% FVC.

Decrease in the ratio of FEF_{25} or FEF_{50} to FVC reflects an "obstructive" defect; an increase may indicate a "restrictive impairment (*8*,*9*).

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